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Residential natural gas price affordability analysis–A case study of Beijing

Y.X. He [*,1], T. Xia, Y.Y. Liu, L.F. Zhou, B. Zhou

School of Economics and Management, North China Electric Power University, Zhu Xin Zhuang, Bei Nong Lu No.2, Changping District, Beijing 102206 China

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A B S T R A C T

In recent years, the demand for natural gas has shown strong growth in China. However, the relative lack of domestic natural gas resources and dependence on gas imports have resulted in rising natural gas prices. In order to ensure market order, the natural gas pricing mechanism must be closely linked to customer affordability. The objective of this paper is to analyse natural gas prices' economic and psychological affordability for Beijing's residents by the income-expenditure elasticity model and the equivalent heating value method, and further to evaluate the comprehensive affordability of the natural gas price by the small-taking and interval-number methods. Finally, it provides some suggestions for the formulation of Beijing's residential natural gas prices.

Contents

1. Introduction

Natural gas and renewable energy have been considered the key elements of a transition to cleaner and more secure energy in the future. In China, more and more industries are paying attention to

* Corresponding author. Tel.: +86 10 51963733; fax: +86 10 80796904.
E-mail address: heyongxiu@ncepu.edu.cn (Y.X. He).

[1] Professor of North China Electric Power University. The main interest is energy economics and management.

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the use of natural gas and renewable energy, especially in the electricity sectors. There are many complementary in the natural gas and renewable energy in the aspects of economy, technology, environment, which are not only from their similarities, such as the benefit to energy saving and environmental protection compared to coal and oil, but also from their differences, such as energy efficiency, people's acceptability and so on [1].

Energy resources are short, and ways of conducting energy management and rational use of renewable energy have become focuses for the Chinese government. Residents of the country also take a supportive attitude towards the development of clean energy because of its positive impact on the environment [2]. Residential natural gas price reform is considered a very important aspect of China's energy price reforms, and has been a matter of widespread concern in the community. Residential natural gas price affordability has always been the primary consideration of natural gas pricing reform for the Chinese government, and it is also focused by the public in the natural gas price hearing. The natural gas tariffs are controlled by the National Development and Reform Commission (NDRC). The ex-factory price of the domestic natural gas is formulated according to the principle of "cost-plus" pricing, while the prices of imported pipeline natural gas and LNG are executed in accordance with the FOB prices of the contract, which leads to different natural gas sources taking different prices. This non-market pricing mechanism to adjust prices according to changes in cost not only leads to variation in the different items of imported and domestic gas prices, but also severely depresses the value of precious domestic natural gas resources. It is difficult for energy prices to correctly guide rational consumption of natural gas, so studying residential natural gas price affordability plays a guiding role in the formulation of policies which are of benefit for the national economy's development and socially sustainable development.

At present, both qualitative analysis and quantitative analysis is being undertaken in the study of energy price affordability. The methods of literature study, questionnaire and mathematical statistics are generally used in the analysis of price affordability. Jelena and Nevenka [3] analysed Slovenian residential willingness to pay for green electricity based on a linear regression model, and concluded that age, household income, education level and environmental awareness are the main factors. Andre et al. [4] took Sweden as the research subject to analyse consumer willingness to pay electricity bills in a study undertaken by mail questionnaire, and the results show that willingness rose with the use of green electricity. Nikolaos et al. [5] studied residential renewable energy price affordability and influencing factors in Crete based on the double-bounded dichotomous choice model, and concluded that each household is willing to pay an average of 16.33 euros for renewable energy for each quarter in the form of an additional tariff. And residents with a high income or strong environmental awareness are willing to pay more than others. Ryan [6] divided the respondents into two types–collective and voluntary payments–and used a dichotomous choice-contingent valuation survey to explore willingness to pay for renewable energy, concluding that collective payment has higher WTP than voluntary payment in the United States' standard renewable energy policies. Jihyo et al. [7] also used the contingent valuation method to analyse residential willingness to pay for renewable energy in South Korean, and found the average household was willing to pay an additional sum of US$1.35 per month. Zhang et al. [8] studied urban residential willingness to pay for green electricity in Jiangsu Province based on contingent valuation method; the average WTP per month ranged from 7.91 yuan/month to 10.30 yuan/month; Yuan et al. [9] used the regression model to analyse residential willingness to pay the different tariffs based on a questionnaire collected in four cities in China, concluding that public's environmental awareness should be raised during the implementation of the different tariff and the additional price that the public will be accept might be slightly lower than 0.05 yuan/kWh. Mou [10] and Yin et al. [11] analysed the natural gas price affordability of various types of consumers based on the equivalent heating value method, finding that there were some differences in affordability for various types of consumers. In addition, some scholars have explored the price affordability of some resources. Taking Chongqing as an example, Wang et al. [12] analysed residential affordability of water price based on the multi-sector discrete choice method, and suggested that if government wants to propose raising the water price, subsidies should be provided for economically disadvantaged families.

In summary, the theoretical research on the natural gas price affordability in Beijing are less at present. This paper divides residential natural gas price affordability into two parts, including residential economic affordability and psychological affordability. Through the income-expenditure elasticity model and the equivalent heating value method, used to analyse residential natural gas economic affordability and psychological affordability respectively, this paper takes Beijing as an empirical study and comprehensively analyses residential natural gas price affordability, further providing some suggestions for the formulation of Beijing's residential natural gas price.

2. Influencing factors of residential natural gas price affordability

Residential natural gas price affordability reflects not only the relative relationship between per capita disposable income and natural gas expenses, but also the ability to accept and afford certain increases in the natural gas price. Residential natural gas price affordability is mainly divided into economic affordability and psychological affordability, which are influenced by per capita disposable income, the price of alternative energy and residential environmental awareness.

2.1. Per capita disposable income

For residents, the higher their disposable income, the higher the natural gas price they are able to withstand. From experience of the world's natural gas market development, when per capita disposable income reaches US$ 1000, residential natural gas consumption will grow rapidly. With economic and social development, per capita disposable income increases gradually, with which residents' natural gas price affordability will also improve significantly.

2.2. The price of alternative energy

Alternative energy to natural gas has two meanings in this paper: the first is other types of energy, including coal, refined oil, liquefied petroleum gas (LPG), electricity and new energy. The higher the prices of these alternative energy sources, the higher the users' willingness to pay for natural gas prices. The other refers to natural gas in surrounding or adjacent areas; the price of alternative energy is made up of the natural gas price in surrounding or adjacent areas and pipeline transmission cost.

Taking China's urban residents as an example, in the first meaning, the household fuels currently used are coal, liquefied petroleum gas, pipeline gas, electricity, etc. If the natural gas price is higher than the lowest price of other isocaloric energy sources, the residential psychological affordability of natural gas prices will be relatively weaker. In addition, new energies such as wind and solar energy have a substitution effect for natural gas due to their energy-saving features. The National Grid Corporation in China launched a free grid connection for new distributed energy to

encourage the use of new energy sources, but it is still difficult to achieve universal access to such new energy because of the higher construction costs and the lower natural gas price. In future, with the technological innovation and national support, the alternative trends will be more obvious between new energy and natural gas resources, at which point residential psychological affordability of natural gas prices will be reduced.

In terms of the second meaning, if the price of natural gas in surrounding or adjacent areas is lower, and the price when adding the pipeline transmission cost is still lower than the price in the region, residents will be more inclined to use natural gas in surrounding or adjacent areas, and residential psychological affordability of the natural gas price will be relatively reduced.

2.3. Residential environmental awareness

Residents' environmental awareness also affects residential psychological affordability of natural gas prices. In China, the government and residents all emphasise the negative impact of environmental issues and consider natural gas as an alternative energy source for the future. If the residents have strong environmental awareness, their psychological affordability of natural gas prices will be relatively higher.

3. Comprehensive evaluation model of residential affordability of natural gas prices

3.1. Evaluation model of residential economic affordability of natural gas prices

Residential economic affordability of natural gas price refers to the urban residents' acceptance to natural gas price based on the comprehensive changes of per capita disposable income, natural gas consumption and its price.

According to the theory of sensitivity analysis of the economics, it is relatively appropriate to use the ratio between the relative changes of various factors as price affordability coefficient. Therefore, we propose to adopt the price affordability coefficient ε to evaluate the residents' bearing capacity of the natural gas price.

$$\varepsilon = \frac{\Delta I / I}{\Delta N / N} \tag{1}$$

where I is the disposable income, N is the natural gas expenses, ΔI and ΔN represent the changes of disposable income and natural gas expenses respectively.

As the residential natural gas price affordability coefficient, when $\varepsilon > 1$, it illustrates that the revenue growth is higher than the natural gas expenses growth and thus the affordability heightens, otherwise it weakens.

To calculate specific natural gas price affordability, it is better to consider adopting the model of income-expenditure ratio. Because of different residential income situations, this paper classifies the different income levels to explore price affordability. This paper adopts the model of income-expenditure ratio. Because of the different income situations among residents, based on the classification of urban residents by income level, this paper divides residents into five categories according to per capita disposable income: low-income residents, low-middle-income residents, middle-income residents, middle-high-income residents and high-income residents.

It assumes that I_i represents the per capita disposable income of the i-th class residents, N_i is the per capita natural gas consumption of the i-th class residents, P_O is the natural gas price, and then $n_i\%$ is the proportion of the per capita natural gas expenses accounting for the per capita disposable income, which can be calculated as formula (2).

$$n_i\% = \frac{N_i \times P_O}{I_i} \tag{2}$$

It assumes that for the i-th class residents, the proportion of the per capita natural gas expenses in the per capita disposable income is no more than$n_{m,i}\%$, so the maximum natural gas price P_e that the i-th class residents can economically afford can be calculated as formula (3).

$$P_e = \frac{n_{m,i}\% \times I_i}{N_i} \tag{3}$$

3.2. Evaluation model of residential psychological affordability of natural gas prices

The price of alternative energy and residential environmental awareness are the two main factors influencing residential psychological affordability of natural gas prices. Firstly, electricity, coal, oil and other energy sources can be used as a substitute for natural gas. From a psychological angle, consumers believe that the monetary payment for buying the same heat from different energy sources should be equal. Therefore, it is suitable to adopt the equivalent heating value method to analyse residential psychological affordability of natural gas price. This means that the price of natural gas could not be higher than the lowest price for consumers to buy isocaloric energy i (excluding natural gas), and the price is also the highest affordable price for consumers to choose natural gas. Secondly, the price of natural gas could not be higher than the price of natural gas in surrounding or adjacent areas, which, plus the pipeline transmission cost, is represented by P_g. Finally, in the comprehensive model, residential environmental awareness should be considered, which is represented by γ. Considering the price of alternative energy and residential environmental awareness, the model of residential psychological affordability of natural gas prices can be expressed as formula (4).

$$P_p = (1+\gamma)\min\{P_i, P_g\}, \; i = 1, 2, \ldots n \tag{4}$$

where P_p is the highest psychological affordable price for consumers to choose natural gas, P_i is the price of energy i (i=1,2,…n) which has the same heat with per unit of natural gas, P_g is the price of natural gas in surrounding or adjacent areas which plus the pipeline transmission cost. And P_i can be calculated as follows:

$$P_i = \frac{H_g}{H_r} \times P_i' \tag{5}$$

where H_g is the calorific value of a unit of natural gas (i.e., the calorific value of per cubic metre of natural gas). H_r is the calorific value of a unit of alternative energy, P_i' is the price of a unit of energy i paid by residents.

3.3. Comprehensive evaluation model of residential affordability of natural gas prices

As can be seen, per capita disposable income mainly has an effect on the residential economic affordability of natural gas prices, and the price of alternative energy and residential environmental awareness mainly affect residential psychological affordability of natural gas prices, which are all shown in the above evaluation models. Since most studies about energy price affordability are oriented towards one aspect, such as economic affordability or psychological affordability, there is a lack of analysis of its comprehensive affordability. This paper uses two methods to

analyse comprehensive residential affordability of natural gas prices, which are shown as follows.

(1) Small-taking method
A small-taking method involves selecting a minimum from a plurality of values, which can be used to analyse residential comprehensive affordability of natural gas prices; that is, to select the minimum value from economic affordability and psychological affordability, which is expressed as follows:

$$P_a = \min\{P_e, P_p\} \tag{6}$$

where P_a is comprehensive residential affordability of natural gas prices and P_e and P_p are the residential economic affordability and psychological affordability of natural gas price respectively.

(2) Interval-number method
Because comprehensive residential affordability of natural gas prices involves residential economic affordability and psychological affordability, it can be described in the form of interval numbers to establish a comprehensive affordability, which is expressed as follows:

$$P_a = [\min\{P_e, P_p\}, \max\{P_e, P_p\}] \tag{7}$$

4. Residential natural gas price affordability in Beijing

4.1. Natural gas market situation and future trends in Beijing

In 2012, the total natural gas and daily peak volume used in Beijing increased significantly, and annual consumption reached 92 billion m^3. During 2011–2015, four gas-fired thermoelectric centres in Beijing will be put into operation and the scale of residential customers will expand. Natural gas consumption in Beijing will continue to increase at a fast rate, from 7 billion m^3 in 2010 to 18 billion m^3 in 2015, and the proportion of natural gas used in Beijing's energy consumption structure will also rise from the current 13.1% to 20%. In addition, the city's per capita natural gas consumption level will rise from the current 380 m^3 per year to more than 700 m^3, and the rate of gasification of natural gas for Beijing's permanent population will reach more than 95% while that in the outer suburbs will reach more than 60%.

To ensure the utilisation of natural gas, steady construction of gas facilities will be carried out, as shown in Fig. 1. The Shanxi–Beijing gas transmission line I–III will be constructed in the initial stage of the Twelfth Five-Year Plan. Subsequently, a number of projects will also be progressively completed, including Shanxi–Beijing gas transmission line IV, the engineering and external underground gas storage construction of Datang coal gas project, the Tangshan Caofeidian liquefied natural gas project and the construction of a gas pipeline to Beijing. By then, the city will form a multi-source and multi-directional gas supply system.

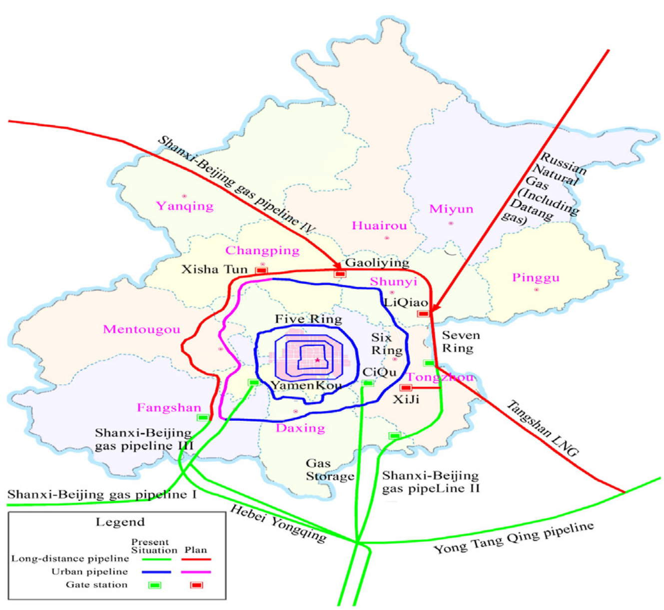


Fig. 1. The natural gas facilities maps of Beijing during the Twelfth Five-Year Plan (2011–2015).

4.2. Residential economic affordability of natural gas prices in Beijing

This paper uses residents' income data for Beijing in 2012 to analyse the economic affordability of natural gas prices. According to statistical data from Beijing Municipal Bureau of Statistics, the annual per capita domestic gas use is 86.13 m^3, and natural gas consumption among different income groups should be different. According to residential per capita gas consumption and natural gas price data in the Beijing Statistical Yearbook of 2012, we roughly estimate the natural gas consumption of the different income groups by a certain percentage, as is shown in Table 1.

Similarly, according to the IEA (International Energy Agency) statistical data, we can obtain residential natural gas prices of the international average level. The residential per capita gas consumption of the international average level can be calculated by the data from BP World Energy Statistics, and the residential per capita disposable income data of the international average level come from the World Bank (data.worldbank.org.cn) statistics database. Based on these data, the proportion of residential natural gas expenses in the income can be calculated. At the international average level, residential gas expenses account for 0.74% of income. Given China's national conditions and Beijing's natural gas market, we take 0.74% as an upper limit (i.e. the proportion of gas expenses in the income should be no more than 0.74%) to calculate the highest affordable gas price for residents in Beijing according to the formula (3), as shown in Table 2.

According to the results in Table 2, the average residential gas price affordability in Beijing in 2012 was 3.13 yuan/m^3. Residents with different income levels have different natural gas price affordability, and the higher the per capita disposable income, the higher the residential economic affordability of natural gas prices. High-income residential affordability is the best, equalling 4.10 yuan/m^3, while low-income residential affordability is the worst and equals 2.76 yuan/m^3. Comparing this with the 2.28 yuan/m^3 seen in Beijing

Table 1
Natural gas consumption estimated values for different income groups in Beijing, 2012.

Item	Citywide	Low-income residents	Low–middle-Income residents	Middle-income residents	Middle-high-income residents	High-income residents
Per capita natural gas consumption expenditure (yuan/year/person)	231.77	160.73	184.35	221.60	260.63	337.10
Natural gas consumption of different groups estimated according to the spending proportion of different groups (m^3/year/person)	86.13	51.48	63.00	81.17	100.21	137.51

Table 2
Highest residential natural gas price affordability of different income groups in Beijing.

Item	Citywide	Low-income residents	Low–middle-Income residents	Middle-income residents	Middle–high-income residents	High-income residents
Per capita disposable income (yuan/year/person)	36469	19194	23884	32739	43182	76186
The highest natural gas price affordability according to the international standard (yuan/m^3)	3.13	2.76	2.81	2.98	3.19	4.10

Table 3
Calorific value of different alternative energy sources and their equal calorific value price.

Fuel name		Current price	Unit	Calorific value	Unit	Equal calorific value price	Unit
Natural gas		2.28	yuan/m^3	36.22	MJ/m^3	2.28	yuan/m^3
LPG	Fair-price gas	2.67	yuan/kg	48.78	MJ/kg	1.98	yuan/m^3
	Negotiated-price gas	5.67	yuan/kg	48.78	MJ/kg	4.21	yuan/m^3
Electricity		0.49	yuan/kWh	3.6	MJ/kWh	4.93	yuan/m^3

in December 2012, it can be seen that the majority of residents can afford the current natural gas prices.

4.3. Residential psychological affordability of natural gas prices in Beijing

LPG and electricity are the main alternative fuels for natural gas. LPG in Beijing has two different kinds of prices: fair-price gas is 2.67 yuan/kg and negotiated-price gas is 5.67 yuan/kg. The calorific value of LPG is about 48.78 MJ/m^3; the calorific value of LPG from Shanxi to Beijing is about 36.22 MJ/m^3. In Beijing, due to the different tariffs currently implemented, this paper takes the first gradient tariff for discussion: the residential electricity price is 0.49yuan/kWh and its calorific value is 3.6 MJ/m^3. As the standard calorific value of natural gas from Changqing to Beijing is 36.22 MJ/m^3, according to formula (2), the prices based on the equivalent heating value method are calculated as shown in Table 3.

From the tendency of the development, the supply of fair-price gas will reduce gradually; eventually, the supply of LPG will be open to the market, and its price will gradually come closer to that of negotiated-price gas. Therefore, we take the average price of fair-price gas and negotiated-price gas, 3.10 yuan/m^3, as the equal calorific value price of natural gas to LPG in Beijing, as the equal calorific value of natural gas to electricity is 4.93 yuan/m^3.

The pace of development and utilisation of new energy and renewable energy in Beijing is accelerating and the scale of new energy industry is expanding. A rapid development of use of solar energy has been achieved, with engineering projects such as “Sunshine double hundred” and “Golden sun”, and biomass energy is developing rapidly, with biogas cogeneration projects in LiuMinYing Village, large-scale biogas power generation projects in DQY and Asuwei landfill gas power generation projects. Moreover, there have been breakthroughs in development and utilisation of wind energy. As the new energy and natural gas are all environmentally friendly, the development of new energy in Beijing has affected residential natural gas prices, especially the development of distributed energy. The National Grid Corporation has introduced a free grid connexion to distribute new energy, and in the future, with technology continuing to progress, new energy's substitution effect on natural gas will become more obvious–also a major factor influencing residential psychological affordability of natural gas prices and leading to decreased affordability. Because of the costly construction of new energy, the difficulty promoting key technologies and the localised applications, new energy has not been used on a large scale, meaning the impact of new energy on natural gas is not currently great.

Table 4
Highest residential natural gas price affordability of different environmental awareness in Beijing.

Item	Residents with weak environmental awareness	Residents with medium environmental awareness	Residents with strong environmental awareness
The natural gas price affordability (yuan/m^3)	3.10	3.255	3.41

Considering the natural gas in surrounding or adjacent areas, residents could not purchase the natural gas directly from the surroundings, and they must purchase the natural gas currently in the natural gas companies. In addition, residential environmental awareness should be considered. This paper divides residential environmental awareness into three situations–weak, medium and strong–and their environmental coefficients are tentatively set at 0, 0.05 and 0.1. Therefore, based on the above analysis and combined with formula (4), residential psychological affordability of natural gas prices with different environmental awareness can be calculated as shown in Table 4.

4.4. Residential comprehensive affordability of natural gas prices in Beijing

Combined with the residential economic and psychological affordability studied above, the comprehensive affordability of natural gas prices for different income groups in Beijing could be calculated in a number of different comprehensive models, as shown in Table 5.

As can be seen, residential economic affordability is more important. The higher the income of the resident, the stronger the comprehensive affordability of natural gas prices. Residential comprehensive affordability with different environmental awareness is also different, and with increased awareness, affordability gradually increases.

5. Prediction of residential natural gas price affordability in Beijing

5.1. Prediction of the per capita disposable income

Due to the uncertainty of social and economic development, there are lots of uncertainties in the long-term prediction of per

Table 5
Residential affordability of natural gas prices in Beijing Unit: yuan/m^3.

Residents of different income groups		Citywide	Low-income residents	Low–middle-Income residents	Middle-income residents	Middle-high-income residents	High-income residents
Residents with weak environmental awareness	Small-taking method	3.10	2.76	2.81	2.98	3.10	3.10
	Interval-number method	3.1–3.13	2.76–3.1	2.81–3.1	2.98–3.1	3.1–3.19	3.1–4.10
Residents with medium environmental awareness	Small-taking method	3.13	2.76	2.81	2.98	3.19	3.10
	Interval-number method	3.13–3.255	2.76–3.255	2.81–3.255	2.98–3.255	3.19–3.255	3.255–4.10
Residents with strong environmental awareness	Small-taking method	3.13	2.76	2.81	2.98	3.19	3.41
	Interval-number method	3.13–3.41	2.76–3.41	2.81–3.41	2.98–3.41	3.19–3.41	3.41–4.10

Table 6
Per capita disposable income of Beijing's low-middle-income households from 2004 to 2012.

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012
The per capita disposable income (yuan/year · person)	10960.8	12485.2	14439	15650	16713	18501	20842	21549	23884
Annual average growth rate (%)	11.84	13.91	15.65	8.39	6.79	10.70	12.65	3.39	1.08

Table 7
Per capita disposable income prediction of low-middle-income households in Beijing **Unit:** yuan/year/person.

Year	Low level (5%)	Middle level (10%)	High level (15%)
2013	25078.20	26272.40	27466.60
2014	26332.11	28899.64	31586.59
2015	27648.72	31789.60	36324.58

capita disposable income. In addition, different income groups have different sensitivity to natural gas prices, so is the economic affordability. Taking low-middle-income residents as an example, this paper uses the method of scenario analysis to predict the per capita disposable income of low-middle-income residents in Beijing.

First, we analyse the per capita disposable income of Beijing's low-middle-income households in recent years. Table 6 shows per capita disposable income from 2004 to 2012.

As can be seen from Table 6, the per capita disposable income of Beijing's low–middle-income households has shown a growth trend and the annual average growth rate is 9.27%. In order to predict low–middle-income residents' per capita disposable income in Beijing, this paper refers to the method of risk prediction; three scenarios will be set up depending on the different annual growth rate, that is, low level (a growth rate of 5%), middle level (a growth rate of 10%) and high level (a growth rate of 15%). According to the three scenarios and per capita disposable income in 2012, we can predict the per capita disposable income of low-middle-income households from 2013 to 2015, as shown in Table 7.

5.2. Prediction of natural gas consumption

According to the data of Statistical Yearbook published by the Beijing Municipal Bureau of Statistics, Table 8 shows the annual per capita domestic gas use of Beijing's low–middle-income households from 2004 to 2012. With the increase of urban population, the natural gas consumption of low-middle-income households has always been an upward trend in recent years, especially in 2010 there is a sharp rise with the growth rate 70.42%. In the end of the Eleventh Five-Year (2006–2010), natural gas consumption has been raised two times as against 2006, and there are 1.15 million new residential customers. The trend of per capita natural gas consumption of 2011 restores to smooth.

Considering Beijing's total population growth and the relative measures to save natural gas comprehensively, we use the average growth rate of 3.34% in the past two years to predict the per capita gas consumption of low-middle-income households from 2013 to 2015, as shown in Table 9.

5.3. Proportion prediction of natural gas expenses in the revenue

According to formula (2), we can calculate the per capita natural gas expenses and per capita disposable income of different income groups from 2008 to 2012, and then obtain the proportion of natural gas expenses in the per capita disposable income, as shown in Table 10.

It can be seen from Table 10 that all the proportions of natural gas expenses in per capita disposable income of different income groups are about 0.5% from 2008 to 2012. Among them, the maximum value is 0.84% for low-income households in 2012, while the minimum value is 0.22% for high-income households in 2008.

Considering the current situation regarding natural gas expenses in Beijing and referring to the relevant statistics, when the proportion of natural gas expenses in per capita disposable income reaches 0.5%, the residents can generally afford it and will begin to care about the amount of natural gas used; when the proportion reaches 1%, the residents will begin to pay more attention to saving natural gas; when the proportion reaches 2%, it will have a large impact on using natural gas and promote residents' attempts to saving gas use reasonably; and when the proportion reaches 3%, it will have a very large effect on residents' use of natural gas. Therefore, this paper only predicts the prices of natural gas under the situations of 0.5% and 1%, which are the two proportions of natural gas expenses in per capita disposable income.

5.4. Prediction of natural gas price affordability

To collect and calculate the per capita disposable income and gas consumption forecast above, the gas price affordability of low-

Table 8
Per capita natural gas consumption of Beijing's low-middle-income households from 2004 to 2012.

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012
The per capita consumption of natural gas(m^3/year/person)	25.46	29.64	31.84	33.67	34.63	34.63	59.02	59.70	63.00
Annual average growth rate(%)	6.22	16.42	7.42	5.75	2.86	0	70.42	1.15	5.53

Table 9
Prediction of per capita natural gas consumption of Beijing's low-middle-income households Unit: m^3/year · person.

Year	2013	2014	2015
Per capita consumption of natural gas	65.10	67.28	69.53

Table 10
Proportion of natural gas expenses in the per capita disposable income of different income groups from 2008 to 2012 in Beijing Unit: %.

Year	Average	Low-income residents	Low-middle-income residents	Middle-income residents	Middle-high-income residents	High-income residents
2008	0.35	0.42	0.42	0.43	0.39	0.22
2009	0.34	0.38	0.38	0.40	0.34	0.25
2010	0.46	0.58	0.58	0.53	0.48	0.33
2011	0.54	0.60	0.62	0.56	0.53	0.41
2012	0.64	0.84	0.77	0.68	0.60	0.44

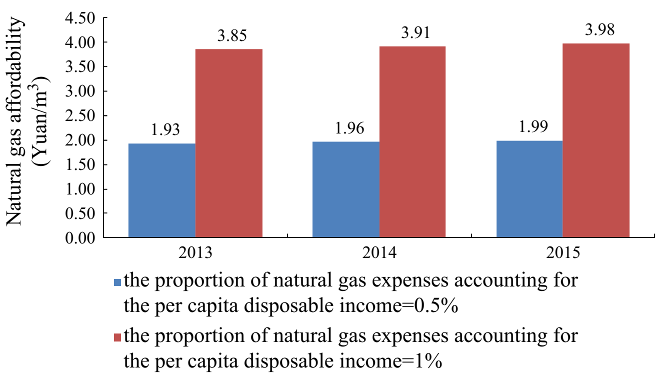


Fig. 2. Low level of gas price affordability.

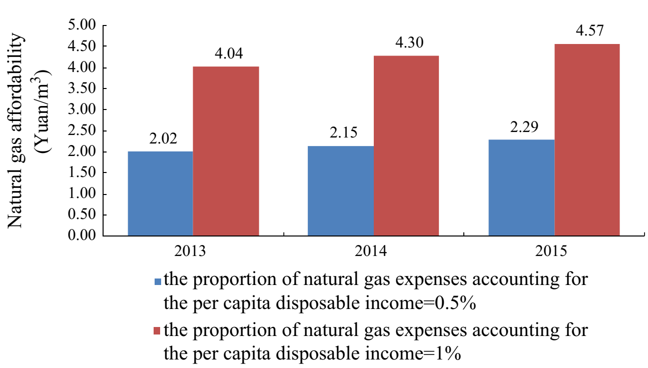


Fig. 3. Middle level of gas price affordability.

middle-income residents in Beijing from 2013 to 2015 can be obtained, as shown in Figs. 2–4.

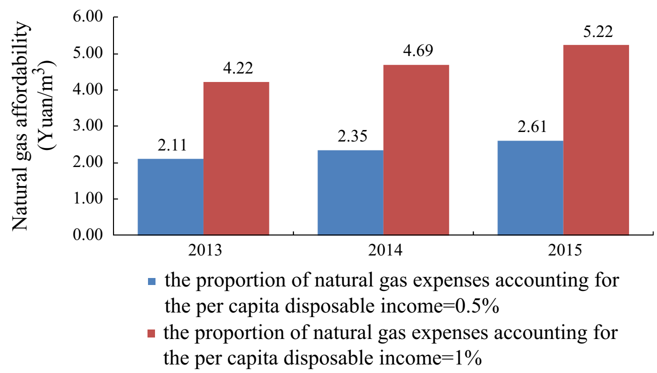


Fig. 4. High level of gas price affordability.

5.4.1. Low level of natural gas price affordability

When the proportion of per capita natural gas expenses is 0.5% in the per capita disposable income, affordable gas prices for low-middle-income residents in Beijing from 2013 to 2015 will be 1.93 yuan/m^3, 1.96 yuan/m^3 and 1.99 yuan/m^3 respectively. This level is acceptable to residents and the gas price may not have a negative impact on their lives.

When the proportion of per capita natural gas expenses is 1% of the per capita disposable income, affordable gas prices for low-middle-income residents in Beijing from 2013 to 2015 will be 3.85 yuan/m^3, 3.91 yuan/m^3 and 3.98 yuan/m^3 respectively. At this level, the residents will pay attention to natural gas consumption and focus on saving it.

5.4.2. Middle level of natural gas price affordability

When the proportion of per capita natural gas expenses is 0.5% in the per capita disposable income, affordable gas prices for low-middle-income residents will be 2.02 yuan/m^3, 2.15 yuan/m^3, and 2.29 yuan/m^3 respectively. This level is also acceptable to residents and the natural gas prices may not have a negative impact on their lives as well.

When the proportion accounts for 1% of the disposable income, affordable gas prices for low–middle-income residents will be 4.04 yuan/m^3, 4.3 yuan/m^3, and 4.57 yuan/m^3 respectively. At this level, residents will also pay attention to natural gas consumption and focus on saving it as well.

5.4.3. High level of natural gas price affordability

When the proportion is 0.5% of disposable income, affordable gas prices for low–middle-income residents will be 2.11 yuan/m^3, 2.35 yuan/m^3, and 2.61 yuan/m^3 respectively. This level is also acceptable to residents and natural gas prices could not cause negative impact on their lives as well.

When the proportion rises to 1%, affordable gas prices will be 4.22 yuan/m^3, 4.69 yuan/m^3, and 5.22 yuan/m^3 respectively. At this level, residents will pay more attention to natural gas consumption and focus on saving it.

6. Conclusions

By establishing the income-expenditure elasticity model and using the equivalent heating value method, this paper analyses the economic and psychological affordability of residential natural gas prices for different income groups and uses two models (small-taking and interval-number method) to evaluate it comprehensively.

As the capital of China, Beijing's response to energy price changes is faster and more intuitive, and its own market price may also become a benchmark for other regions. Therefore, this paper takes Beijing as its example. Considering per capita disposable income, the price of alternative energy and residential environmental awareness, this paper concludes that residents with different environmental awareness have different comprehensive affordabilities of natural gas prices. For residents with a medium level of environmental awareness, the average gas price affordability of Beijing based on the model of small-taking is around 3.13 yuan/m^3, and based on the interval-number model it is around 3.13∼3.255 yuan/m^3. We suggest that the natural gas price should be adjusted mainly according to the affordability of different income groups, with the economic levers used like tiered pricing for household natural gas to limit high-income groups' consumption of natural gas resources and finally achieve the purpose of saving natural gas. In addition, along with the increasing development of new energy technologies and the strengthening of financial subsidies, in the alternative energy, the distributed renewable energy will play an increasingly substitution effect on the natural gas, which leads to decline of residential affordability of natural gas in Beijing, but, in the present situation, natural gas still plays a greater role than the renewable energy.

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